Dr. William Thornton and the Development of the Mass Measurement Device for Spaceflight

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Research using bedrest and water immersion before Project Mercury indicated that fluid shifts and diuresis would occur after several days in weightlessness.[3] This was confirmed by noting postflight weight loss in almost all the Gemini and Apollo crewmembers. The importance of being able to determine body mass during long duration spaceflight was recognized as early as 1964 when NASA-funded contractor studies both indicated the importance for documenting biological fluid shifts and established that harmonic motion could be used to determine mass in weightlessness.[5]

From 1965–1967, in conjunction with the development of life sciences research equipment for the joint U.S. Air Force/National Reconnaissance Office Manned Orbiting Laboratory (MOL) Program by the Aerospace Medical Division of Brooks AFB, San Antonio, TX, Dr. William Thornton developed a device using spring-driven harmonic motion to quantify the mass of an oscillating specimen. The oscillatory period of the spring was a function of the amount of mass on the device. The period could be measured electro-optically and electronically converted to a direct mass read out. Dr. Thornton demonstrated a prototype device (**Fig. 1**) to the Space Medicine Advisory Group at NASA Headquarters. This group was chaired by Dr. Sherman P. Vinograd and was responsible for coordinating the biomedical research program for the MOL program of the Air Force and the Apollo Applications Program (later, Skylab) of NASA.[2] The prototype used in the presentation to the Vinograd group in 1966 is in the Thornton Archives at the University of Texas Medical Branch Library in Galveston, TX.

Development by NASA continued after cancellation of the MOL program and resulted in reliable devices with high accuracy (0.1–0.01%) to measure both astronaut and specimen mass during the Skylab missions. Skylab carried two small Specimen Mass Measurement Devices with sample mass limits of 1 kg for Experiment M074, "Specimen Mass Measurement" and one Body Mass Measurement Device (BMMD; **Fig. 2**) with a 100-kg mass limit for Experiment M172, "Body Mass Measurement." Measurements of astronaut mass changes on the first Skylab mission documented an early in-flight weight loss of 3–4% which was quickly recovered postflight.[12] Based on this data, Dr. Thornton and Dr. John Ord concluded that, with increased diet and exercise on the later and longer Skylab flights, the weight loss which occurred slowly throughout the remainder of the flight plateaued and was not as great as on the first flight. Leg volume measurements on later Skylab and Shuttle crewmembers showed a decrease in leg volume due to cephalad fluid shifting and diuresis that accounted for the early body mass changes.[1,6,11]

Records are incomplete, but we believe there were five M172 units built for the Skylab program:

- The flight unit (Fig. 2) launched on Skylab in 1973 and was lost when Skylab's orbit decayed in 1979.
- The flight backup, which was flown on Shuttle missions SLS-1 and SLS-2, and is now assumed to be in the unflown backup Skylab in the Smithsonian's National Air and Space Museum (NASM).
- The design verification test unit, presumably in the NASM.
- The qualification unit, also presumably in the NASM.
- The crew training unit for the Skylab one-G trainer on display at Space Center Houston (the official visitors' center for NASA's Johnson Space Center).

According to Dr. Thornton, the BMMDs flown on Skylab and Spacelab were the same design as was planned for the MOL.[10] A prototype built by Henry Whitmore of San Antonio, TX, for Brooks AFB (Charles Sawin, personal communication; August 2018)—which Dr. Thornton retrieved as surplus from Brooks AFB—was last reported in the possession of Dr. Yusako Fujii at Gunma University near Tokyo, Japan.

Mass measurement devices were used on the Shuttle and several Soviet/Russian space stations: the Skylab backup device was flown on two dedicated Spacelab Life Sciences (SLS) missions STS-40 SLS-1 (1991) and STS-58 SLS-2 (1993); the more compact and simpler Space Linear Acceleration Mass Measurement Device (SLAMMD; **Fig. 3**) was tested on STS-69;[9] and the Russian M08 BMMD (**Fig. 4**) on the Soviet Salyut and Mir space stations starting with Salyut 5 and 6.[7] Today the M08 currently provides the primary in-flight body mass measurement capability on the International Space Station (ISS) with SLAMMD being held in reserve. Both systems have consistently shown an average of 2.8–4.4% weight loss attributed to fluid loss early in flight and possibly due to inadequate caloric intake with time in spaceflight.[14] A domestic reproduction of NASA's SLAMMD was also built by the Chinese space program[4] and was demonstrated during spaceflight aboard its Tiangong-1 space laboratory.

The guiding principle of these mass measurement devices is Sir Isaac Newton's Second Law of Motion: force is equal to mass times acceleration. For the SLAMMD, the force is generated by two sets of springs. The linear acceleration along a short track is measured by a precise optical instrument which detects the

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This feature is coordinated and edited by Mark Campbell, M.D. It is not peer-reviewed. The AsMA History and Archives Committee sponsors the Focus as a forum to introduce and discuss a variety of topics involving all aspects of aerospace medicine history. Please send your submissions and comments via email to: mcamp@1starnet.com.

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DOI: https://doi.org/10.3357/AMHP.5276.2019

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AEROSPACE MEDICINE HISTORY, *continued*

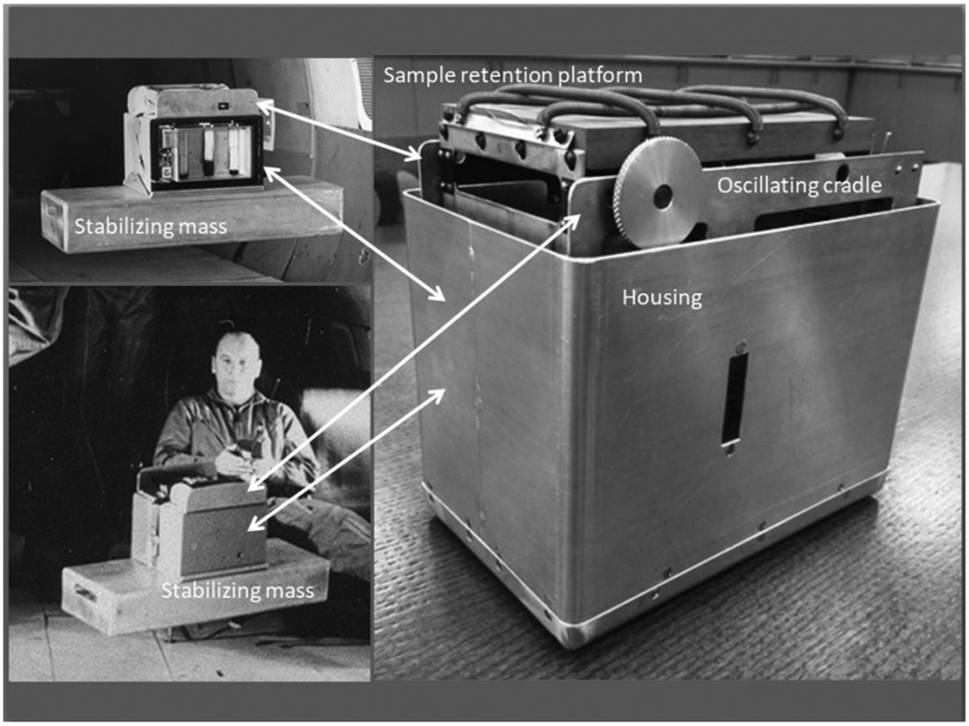

Fig. 1. The circa-1965 demonstration version of the mass measurement device built by Dr. William Thornton and colleagues at Brooks AFB. Left, top and bottom: Front and back views of the device being evaluated in brief weightlessness during parabolic aircraft flight (courtesy of Dr. William Thornton). Right: Similar device now in the UTMB Archives (courtesy of Dr. Robert Marlin).

position vs. time trajectory of the SLAMMD guide arm. The average acceleration is calculated with regression analysis. The final computation is done via a portable laptop computer with SLAMMD-unique software. The Skylab M172 and Russian M08 devices are based on the principle that the mass of a body constrained to oscillatory motion is inversely related to the square of the period of that body's oscillation in response to a perturbation. The devices displayed a time count that was converted to mass. The differences between the original Skylab M172 device and those in use now on the ISS have been described elsewhere by Dr. Thornton.[10]

Interestingly, the long modules on ISS with relatively open interiors now allow a simpler method of mass determination in weightlessness, as proposed by Dr. Fujii of Gunma University. This method involves the application of the spring constant to gently accelerate the astronaut or other test mass slowly the length of the module, with a measurement of travel time over the known distance under the force of the calibrated spring, allowing the calculation of mass. This technique has been demonstrated but is not in regular use.[8]

Information analogous to, but different from, body mass might be acquired on a noncontact basis using a camera system to image the astronaut's body. The camera system is based on the Kinect motion sensing input device used in games. The internal volume of a 3D model of an astronaut can be cross-referenced with a statistical model of almost 30,000 people to predict the astronaut's weight to within 3%.[13] This technique assumes that changes in whole body density during spaceflight are negligible, which may be the case for healthy astronauts after the initial period of mass loss during acclimation to the spaceflight environment.

Dr. Thornton was uniquely qualified to develop the first mass measurement device. He received a Bachelor of Science degree in physics from the University of North Carolina at Chapel Hill in 1952 and was then the officer-in-charge of the Instrumentation Lab at the Air Force Flight Test Air Proving Ground. Before attending medical school, he was the chief engineer of the electronics division of the Del Mar Engineering Labs in Los Angeles from 1956 to 1959. Dr. Thornton was selected as a NASA scientist-astronaut in 1967 and believes that part of his success in being selected as an astronaut was because NASA wanted his mass measurement devices. He was the physician crewmember on the highly successful Skylab Medical Experiments Altitude Test, a 56-d altitude chamber simulation of the Skylab mission enabling crewmen to collect medical experiments baseline data and evaluate equipment, operations, and procedures in an environment which closely matched spaceflight except for weightlessness. He was an astronaut support crewmember for Skylab as well as a Principle Investigator for several of the biomedical Skylab experiments. He later flew on two Shuttle missions and continued to be the Principal Investigator on many Shuttle investigations. His painstaking efforts over several years in championing mass measurement development resulted in successful in-flight hardware that produced accurate data and rapidly increased our knowledge of human spaceflight physiology.

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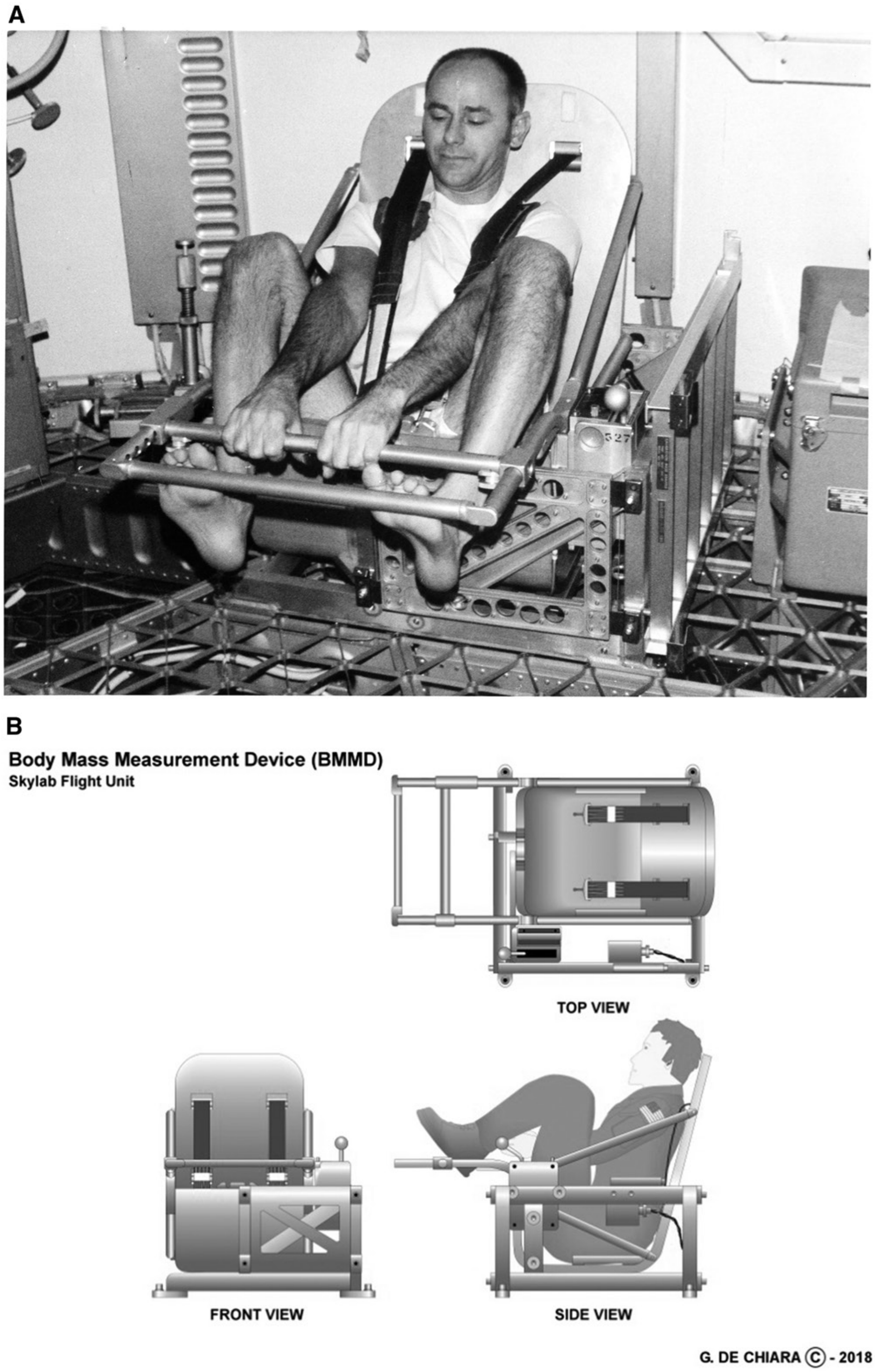

Fig. 2. Top: The Skylab Body Mass Measurement Device (BMMD) in use aboard Skylab 3 by Alan Bean for investigation M172 (courtesy of NASA). Bottom: Three-way view of M172 BMMD (courtesy of Giuseppe de Chiara).

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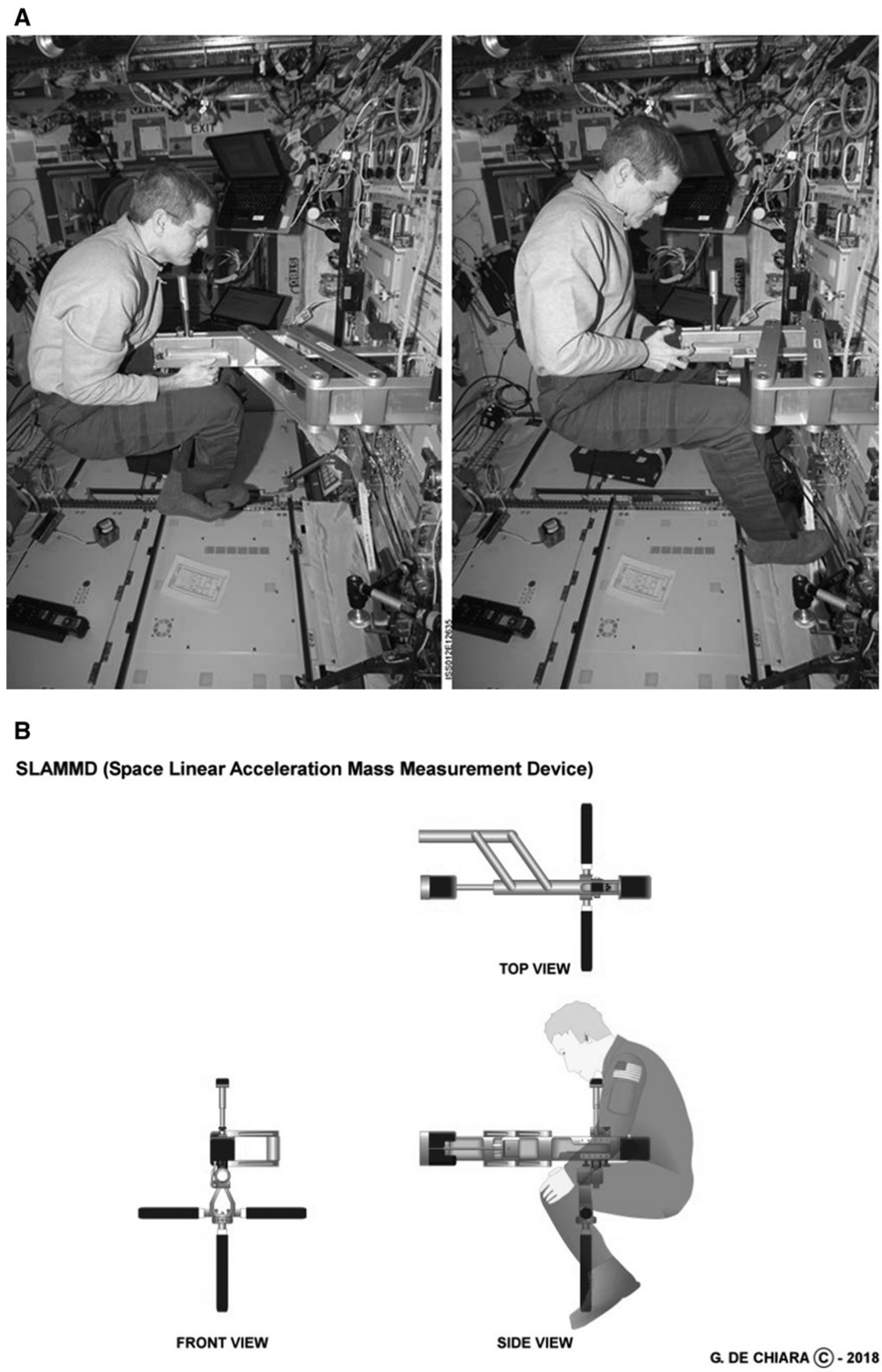

Fig. 3. Top: The Space Linear Acceleration Mass Measurement Device (SLAMMD) in use on ISS by William McArthur (courtesy of NASA). Bottom: Three-way view of SLAMMD (courtesy of Giuseppe de Chiara).

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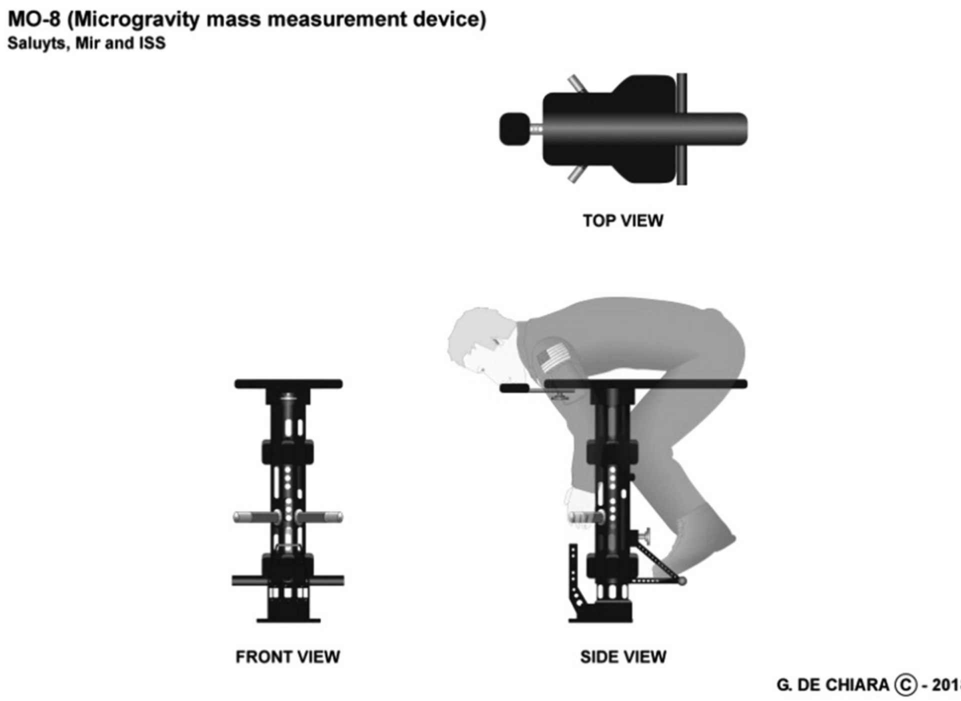

Fig. 4. Three-way view of M08 device for body mass measurements used on Soviet and Russian space stations starting with Salyut 5 in 1976 (Courtesy of Giuseppe de Chiara).

ACKNOWLEDGMENTS

The authors thank Dr. Charles Sawin and Dr. Melvin Buderer for helpful comments and recollections about Skylab experimental hardware and Dr. Robert Marlin for photographs of artifacts in the Thornton Archives.

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